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Challenges for biodiversity research in Europe

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Summary

- In 2010, the international year of biodiversity, new policies for preserving biodiversity in Europe and worldwide will be developed as targets set by older policies, such as to halt biodiversity loss in the EU by 2010, were not met. This paper aims at sharing the expertise LERU's members harbour to set the right priorities for new biodiversity policies.

- Three key observations point to the urgency of an effective biodiversity conservation policy: 1) the alarming global decline in biodiversity; 2) the associated diminishing return in ecosystem services that are key to human well-being; 3) the dangerous mix of climate change and biodiversity loss.

- There are important gaps in our knowledge of the regulating mechanisms of biodiversity and the relationship of biodiversity to ecosystem services. We therefore list 18 research challenges, which we consider to be the 'need-to-know' building blocks for a future research agenda. Filling the knowledge gaps is crucial to develop an efficient and sustainable policy towards biodiversity conservation.

- The research challenges are broadly grouped in five areas. A first set focuses on different challenges posed by documenting and monitoring biodiversity. A second group describes six research challenges on drivers of biodiversity that need more attention. These challenges relate to 1) insight into the processes of community assembly; 2) large and complex ecosystems; 3) landscape metapopulation structure; 4) eco-evolutionary dynamics; 5) species networks and identifying its key players; and 6) issues associated with complex dynamics and alternative stable states. The challenges of linking biodiversity, functional diversity, and ecosystem functioning and services are set out in a third group of research challenges, which also highlights the need to analyse ecosystem services at landscape level and to investigate the economics of biodiversity and ecosystem services. A fourth set of research challenges focuses on understanding how species respond to anthropogenic impact (global change), and a fifth group emphasizes the need to understand how species respond to nature conservation measures.

- Besides describing important research challenges, LERU also provides recommendations for effective biodiversity conservation strategies, which are not only aimed at policy makers, but also at researchers, other stakeholders and the general public:

- It is necessary to **invest in a European infrastructure for biodiversity data and research.** LERU emphasizes the importance for Europe to invest in adequate infrastructures which support biodiversity research to increase our knowledge on biodiversity and its impact on the functioning of ecosystems, and hence help decision makers in devising cost-effective management plans to reach the stated goals.

- There is a need for a **powerful research agenda enhancing fundamental knowledge on biodiversity drivers and threats**. This vigorous biodiversity-targeted research programme should be initiated at the European level, but also with strong national support.

- There is a great need for an **effective translation of scientific knowledge into biodiversity practice** to guarantee that scientific evidence is available to inform both policy development and practical implementation of conservation management.

- There is a need for a **consistent and global biodiversity conservation policy**, which aims at changing the way people live and work in Europe to ensure biodiversity conservation within but also outside Europe's borders.

- Given that biodiversity and ecosystem services are of paramount importance to the development of human societies in the long run, **a "biodiversity check" in all policies** should be implemented.

- When future biodiversity conservation strategies are

developed, it should be verified if the measures taken are **climate change-proof.**

- **The economic consequences of biodiversity loss and gain need to be quantified** to enable a system in which the agent causing the loss will need to pay for the costs linked to the loss and the restoration of ecosystems, instead of society as a whole.

- Prevention is by far the most efficient strategy to reduce the number of invasive exotic species and their negative impact on biodiversity. To realise efficient prevention, a **European strategy to deal with invasive exotic species** is mandatory.

- LERU emphasizes the importance of collaboration across scientific disciplines for modern biodiversity research and therefore emphasizes the need for **support for multidisciplinary collaborative networks**.

- LERU calls for **an improved science-policy interface in biodiversity protection**, which could be realised by reinforcing the existing Intergovernmental platform on Biodiversity and Ecosystem Services (IPBES).

- Increased efforts for raising **biodiversity education and awareness** are necessary to get the needed support from society as a whole for a successful biodiversity policy. Research-intensive universities can play a leading role in this.

- Research-intensive universities can contribute to fighting biodiversity loss by implementing an ambitious biodiversity research agenda, by developing inter-university networks sharing research infrastructures, and by investing in biodiversity education. LERU considers the study of biodiversity and the ecological responses to environmental change a top priority with an enormous added value to society.

Challenges for biodiversity research in Europe

I. Introduction

1. In 2010, the UN Year of Biodiversity, the European Union is determined to set new goals for its policy to preserve biodiversity in Europe and elsewhere. These new goals are necessary as the target the EU set in 2001, to halt biodiversity loss in the EU by 2010, will not be reached[1]. The same conclusion was reached in The Global Biodiversity Outlook 3, published in May 2010 by the Convention on Biological Diversity (CBD). The report concluded that we can no longer see the continued loss of, and changes to biodiversity as an issue separate from the core concerns of society[2]. By the end of this year, the European Commission wants to present a new EU biodiversity strategy. A first step towards that objective is the Communication[3] the EC published in January which sets out "Options for an EU vision and target for biodiversity beyond 2010". The document provides a brief but adequate list of the status and trends of biodiversity in Europe and globally, of the implications of biodiversity loss and of the achievements and shortcomings of the current policy. It also sets out an EU vision for 2050[4], which has been agreed upon by the EU Environment Council at their meeting on 15 March 2010. The environment ministers also agreed to "halt the loss of biodiversity and ecosystem services in the EU by 2020 and restore them insofar as possible, and step up the EU's contribution to averting global biodiversity loss" [5]. This 2050 vision and 2020 target were taken up in 'Europe 2020: a new European strategy for jobs and growth', as adopted by the European Spring Council on 25/26 March[6]. The

1 A detailed indicator-based assessment of progress towards halting biodiversity loss by 2010 in the EU can be found in the EEA Report No 4/2009 'Progress towards the European 2010 biodiversity target'.

2 See http://gbo3.cbd.int/

3 COM(2010) 4 final, Brussels, 19 January 2010. This Communication was published in the light of a conference, organised by the Spanish EU Presidency at the end of January, on "Post-2010 Biodiversity Vision and Target – The role of Protected Areas and Ecological Networks in Europe". At the conference 10 "Cibeles" priorities for political action were identified.

4 The EU vision for 2050, as proposed in COM(2010)4 final and accepted by the EU environmental council, is 'Biodiversity and ecosystem services – the world's natural capital – are preserved, valued and, insofar as possible, restored for their intrinsic value and so that they can continue to support economic prosperity and human well-being as well as avert catastrophic changes linked to biodiversity loss.'

5 This 2020 headline target was the most ambitious option the European Commission listed in their Communication. The four options were 1) Significantly reduce the rate of loss of biodiversity and ecosystem services in the EU by 2020; 2) Halt the loss of biodiversity and ecosystem services in the EU by 2020; 3) Halt the loss of biodiversity and ecosystem services in the EU by 2020 and restore them insofar as possible; 4) Halt the loss of biodiversity and ecosystem services in the EU by 2020 and restore them insofar as possible, and step up the EU's contribution to averting global biodiversity loss.

new EU biodiversity strategy, for which the 2050 vision and 2020 target will form the basis, will also serve as the EU input in the 10th Conference of the Parties of the UN Biodiversity Convention, to be held in Nagoya, Japan, second half of October 2010. In a conference, organised by the Spanish Presidency of the EU in January 2010, a first, important step towards a new EU biodiversity policy was taken by the definition of the so-called "Cibeles" priorities[7] for political action to halt biodiversity loss in Europe, which are listed in Box 1.

2. Given these European and international policy developments, and the fact that its member universities harbour much expertise in the field of biodiversity research and harbour the larger part of the world's herbaria and natural history collections covering the Earth's biodiversity, LERU considered it important to publish an advice paper highlighting opinions for research themes and biodiversity conservation policy options that are of key importance for reaching the ambitious goals of halting biodiversity loss and restoring biodiversity and ecosystem services.

3. In this paper, a working group of biodiversity scholars from the LERU member universities gathered the ideas they consider to be the most relevant for the future biodiversity policy and which are, in their opinion, often given insufficient attention in terms of research development and/or application for the development of biodiversity policy. In a first part, key statements on the challenges of the decline of biodiversity are highlighted. A second part focuses on the contribution scientific research can make to the understanding of the main drivers of changes in biodiversity and consequences for ecosystems. This knowledge is essential for effective biodiversity conservation and sustainable management of natural resources in the future. This second part wants to draw the attention of policy makers, science managers as well as scientists, and provides building blocks for the development of a research agenda on biodiversity. In a third and final part, key points for an integrated and effective biodiversity conservation policy and management are set out. LERU here makes specific recommendations to both national and supra-national policy makers, and highlights the involvement of research-intensive universities.

Box 1: "Cibeles" priorities [6]

1. To incorporate the objectives and targets for biodiversity as part of the European Union Strategy for 2020, which will replace the Gotemburg and Lisbon Strategies.
2. To ensure payment for ecosystem services.
3. To deepen the integration of biodiversity into agriculture, fishing, energy, transport and development studies. Improving ecological connectivity and adaptation to climate change.
4. To fully apply the Birds and Habitats Directives of the European Union and to complete the establishment of the Natura 2000 and Emerald Networks.
5. To preserve the marine environment.
6. To urgently adopt concrete measures to efficiently tackle the problems related to deforestation, to forest, soil and water resources degradation and to the introduction of invasive alien species.
7. To support the establishment and management of protected areas and ecological networks in third countries.
8. To boost the integration of scientific knowledge into decision making processes.
9. Reform the global environmental governance system.
10. Establishment of European Action Plans to achieve the 2020 target.

6 http://www.consilium.europa.eu/ueDocs/cms_Data/docs/pressData/en/ec/113591.pdf
7 http://www.countdown2010.net/2010/wp-content/uploads/Prioridades_Cibeles_eng.pdf

II. Setting the scene: key observations on the challenges posed by the decline of biodiversity

Global decline in biodiversity is alarming

4. Biodiversity is declining rapidly in various parts of the world. Even though there was a clear intention of the international community to reduce biodiversity loss by 2010 and some measures have been taken, recent assessments involving a multitude of indicators show that the rate of biodiversity loss does not appear to be slowing[8]. Habitat destruction and degradation (including pollution), overharvesting of wild populations, climate change, and invasive exotic species are major direct drivers of biodiversity loss. Next to these "big five", however, we need to be vigilant about novel threats[9]. At the root of these threats to biodiversity are the fast population growth of humanity, the per-capita increase in consumption of natural resources, and unsustainable marine and land management practices. The latter is partly the result of population growth itself and partly due to insufficient attention for better alternatives, lack of conceptual breakthroughs and technological innovations, and focus on short term profit rather than long term economic potential.

Global decline in biodiversity is associated with a decline in ecosystem services

5. The global decline in biodiversity leads to associated declines in the services provided by ecosystems that support human societies[10]. Declines in ecosystem services are increasingly being documented, and are often direct and obvious, for example in the case of the decline in fish stocks, loss of carbon storage due to deforestation[11], and problems to obtain sufficient safe drinking water. Taken further, ecosystem degradation and biodiversity loss may result in a threat of human well being and even in the destabilization of societies. Although the problems associated with erosion, flooding and water shortage may in the first place reflect degradation of ecosystems, biodiversity may have an important, but under-studied, effect on vital ecosystem functions[12], including ecosystem resilience[13,14] and adaptability. Biodiversity may act as an insurance and buffer against loss of ecosystem functioning in changing and unpredictable environments. Many of the ecosystem services provided by natural and culturally shaped ecosystems (e.g. agricultural production systems) are irreplaceable, or the technology necessary to replace them is prohibitively expensive. As the human population grows, the role of both natural and man-made ecosystems in maintaining these services becomes increasingly important for human welfare.

Interactions between climate change and biodiversity loss

6. There is an unambiguous and disturbing relation between biodiversity loss and climate change. Climate goals, such as reducing greenhouse gas emissions and sequestering carbon in ecosystems, may not be reached if ecosystems are under stress and function poorly. Conversely, climate change enforces important additional stress on ecosystems, for example through changes in temperature, precipitation patterns and disturbances regimes, and associated changes in biotic interactions[15]. Climate change will also enhance the spread of pest species to new areas, affecting species interactions and causing considerable biodiversity and economic losses. Importantly, indirect consequences of climate change that are mediated by human societies' responses to changes in temperature and precipitation may result in strong additional effects. Increased drought in the Mediterranean will, for instance, lead to a growing water shortage, which may lead to an even stronger reliance on irrigation agriculture, further increasing stress on ecosystems and ultimately leading to further reductions in ecosystem functioning. These different mechanisms result in adverse feedbacks, in which climate change and biodiversity loss can reinforce each other in a

8 Butchart et al. 2010; Global Biodiversity Outlook 3, http://gbo3.cbd.int/
9 Sutherland et al. 2010
10 see Millenium Ecosystem Assessment; http://www.millenniumassessment.org
11 Strasbourg et al. 2009
12 Cardinale et al. 2006; Naeem et al. 2009; Duffy 2009
13 Resilience is the capacity of a system to recover from disturbance
14 Thompson et al. 2009
15 Svenning & Condit, 2008

downward spiral. In dealing with and trying to mitigate climate change, there is thus an important role for ecosystem and biodiversity conservation. Measures to protect ecosystems aimed at preserving their regulation services will be essential in our efforts to adapt to and mitigate climate change.

7. It follows from the above, that biodiversity conservation and climate change mitigation and adaptation should be major priorities in European policies. Any policy on biodiversity (and climate change) should be embedded in the social and economic policies at the level of the EU and its member states. Enforcing corrections on social and economic policies in an effort to decrease biodiversity loss that may be caused by socio-economic development may not be the optimal strategy. Instead, maintenance of biodiversity in both natural and production ecosystems has to be viewed as a key factor that may improve social and economic policies to achieve sustainable development of European societies. Indeed, biodiversity has an important social and economic value and provides indispensable services to human societies. Our future well-being critically depends on its knowledge and maintenance, just like it depends on mitigation of climate change. Unfortunately, the way society recently responded to, for instance, the over-exploitation of marine fish stocks and the critical status of some fishing resources such as blue-fin tuna suggests that there is a long way to go.

III. Research challenges

8. Understanding the regulating mechanisms of biodiversity is key to biodiversity conservation. Ecosystems are dynamic complexes of organisms interacting with their environment and with each other, and these complex dynamics determine ecosystem characteristics and functions. Organisms respond to environmental triggers in their habitat and this affects their functioning. Such functional responses have an impact at the population level, causing shifts in species abundances. This alters the interactions between species and thus affects ecosystem functions. Only by understanding these mechanisms of responses and interactions we will be able to adequately steer conservation of biodiversity. There are important gaps in our knowledge on biodiversity, biodiversity loss and its relationship to ecosystem services[16]. These "research challenges", as listed hereafter, are important and often insufficiently recognized. LERU considers them to be the 'need-to-know' building blocks for a future research agenda, often requiring a multifaceted approach. They are grouped below in broad categories: the first three categories list specific challenges that need to be addressed, while the last two emphasize the need for integrated research on responses to anthropogenic stress and conservation management.

A. Broadening the scope of documenting and monitoring biodiversity

Modern approaches to the inventory of biodiversity

9. In a time when biodiversity is vanishing at an alarming rate, the inventory of the diversity of species and the reconstruction of the Tree of Life is still far from completion. In effect, we do not even know what the diversity is that we are losing. Approximately 1.8 million species are described, which is less than 50% for most groups of organisms and in some cases less than 10% of the estimated number of species (also in very species-rich groups such as the insects, nematodes and many other invertebrates and micro-organisms). Species diversity in ecosystems such as the deep oceans, soils and tropical rainforests is still poorly documented. It is disconcerting to see that taxonomy[17] and the establishment of primary databases or collections are largely ignored in research agendas. Studies on biodiversity should integrate trait-based (e.g. morphology) and genetic approaches (such as genetic barcoding) in taxonomy, and should make use of the full range of modern web-based biodiversity informatics to ensure this information is as widely available as possible.

Diversity, biogeography and ecology of micro-organisms

10. The taxonomy of micro-organisms[18] is extremely

16 COM(2010)4 also acknowledges the existence of significant knowledge and data gaps at all levels

17 taxonomy: the science of naming, describing and classifying organisms in an ordered system that reflects the genetic relationships

18 including prokaryotes, unicellular eukaryotes and fungi

challenging because of methodological constraints in identifying and culturing species. In bacteria, horizontal inheritance adds another layer of complexity. The rapid increase in molecular resources now allows studies on functional diversity and microbial community genomics. This will also aid in unravelling the role of micro-organisms in mutualistic and antagonistic interactions with plants and animals, and their role in terrestrial as well as aquatic communities. To better capture and predict diversity patterns in microbial organisms, it will be important to understand the degree to which general patterns that are observed for macro-organisms (e.g., biogeographical structure, assembly rules, scaling laws) also hold for micro-organisms and to what extent they need to be adapted to include different temporal and spatial scales. The extreme diversity of micro-organisms in soils not only implies many technological challenges, but also calls for an integrated systems approach to understand the relation between diversity and function.

Documenting species distributions

11. There is a need for comprehensive information on species distributions that can act as baseline data for subsequent monitoring studies addressing the impact of environmental change. Detailed species distribution maps combined with measures of relevant environmental conditions are also important to reconstruct ecological niches of species. These data can subsequently be used to parameterize species distribution models, and make inferences on, for instance, the impacts of global warming on future distributions or the relations between climate change and biological invasions. Data on species occurrences come from national and regional governments, scientists, but to a large extent also from the enormous efforts of dedicated volunteers organized in focal groups (documenting plants, birds, insects, etc.). The latter efforts are rarely coordinated at the European level, hampering interpretation beyond national borders, and receive limited support and recognition. 'Citizen Science' projects, supported by modern IT, are a relatively new and promising way to involve more people in gathering better quality data.

The need for long-term monitoring studies

12. All the above issues and the global and pervasive impact of human activities on ecosystems and biodiversity emphasize the importance of long-term datasets for our capacity to document and understand ecosystem changes through time in a quantitative way. Such monitoring will provide the needed understanding for corrective measures. There is an absolute need to continue efforts in Long Term Ecosystem Research (LTER) sites, both marine and terrestrial, as well as to incorporate biodiversity monitoring in existing large-scale grid-based inventories (e.g. forest monitoring at Level-II sites; see also the new National Ecological Observatory Network in North America). In monitoring, it is a major challenge to combine the need for continuity in the data set with sufficient flexibility to incorporate new insights and concepts (e.g. indicators for ecosystem functions and services) as well as new threats[8]. Research should also aim at further developing the European biodiversity indicators that are being produced by EEA[19]. An important challenge is to achieve the ATBI+M approach (All Taxa Biodiversity Inventory and Monitoring). In addition, there is also a need to strengthen the already existing environmental tissue collections, or to create new ones, that provide baseline material to allow retrospective analyses when techniques improve or when there are new findings[20]. This is important for a variety of studies that range from the assessment of the previous occurrence of a given pollutant or an infectious agent, to the retrospective assessment of temporal trends in pollutant levels, environmental temperature, food availability or food web structure.

The need for a common eScience infrastructure for biodiversity research

13. A large amount of data and biodiversity information has been gathered by projects funded by national and international research councils, often in collaborative networks of excellent quality. At the moment, integrative research that addresses fundamental scientific questions as well as important societal issues (for instance on land use, climate change mitigation and urban developments) is ham-

19 http://www.eea.europa.eu/themes/biodiversity

20 Becker et al. 2006; http://www.nist.gov/cstl/analytical/marineesb.cfm

pered by the fact that the data is often heterogeneous, uses different standards and protocols, and is located in isolated data repositories. Acquisition of funds for data analyses is commonly much more difficult than for data collection. Biodiversity research would greatly profit from a synthesis of the data on taxonomic identity, species' indicator values, geophysical data, distribution data, climate data, remote sensing observations, and sensor networks. The transition to a transparent, efficient, open access infrastructure where data, resources, analytical and modelling tools and, foremost, people and expertise come together is imperative to meet the challenges of the future[21].

B. Under-appreciated complexity and scale issues

Understanding the processes of community assembly

14. Despite the large amount of observations on biodiversity patterns in many ecosystems, we still have no detailed understanding of the processes that determine species composition in biological communities, nor what precisely determines the distribution of species. We need further testing of the basic theories on community assembly[22], analyses of the interactions between local population dynamics, regional (meta)populations and regional species pools, and assessments of the predictive power of Species Distribution Modelling (SDM)[23] for multiple species.

The challenges of research on large and complex ecosystems

15. Large ecosystems are generally more diverse than smaller ecosystems, but also allow for more (inter)specific interactions and coevolution, thereby increasing the complexity of these ecosystems[24]. Methodological challenges have hampered large-scale experiments in forests and marine systems, while it is difficult to unequivocally establish relationships (e.g. between biodiversity and ecosystem function) in mechanistic terms from observational studies[25]. Biodiversity-ecosystem functioning studies in forests appear particularly important since they represent the least modified terrestrial ecosystems in Europe that are very important for native biodiversity. The establishment of large-scale long-term tree species assemblage studies[26] across Europe and globally may prove invaluable in fostering a breakthrough in understanding the role of biodiversity for forest ecosystem services. Similarly, the size and complexity of marine ecosystems poses important challenges for mechanistic studies on the relationship between biodiversity and ecosystem stability and function, while the integrity of the system is heavily impacted by climate change, pollution, eutrophication and overharvesting.

Landscape metapopulation structure

16. Habitat fragmentation and other stressors are leading to smaller and more isolated populations, which in turn are more susceptible to stochastic processes of genetic erosion and local extinction. This has important consequences on population viability, and can lead to a hidden extinction debt[27]. Small effective population sizes may result in a sudden instead of a gradual population collapse at a critical level of inbreeding. European conservation policy, especially with regards to the Favourable Conservation Status (FCS) of species of the Habitats Directive[28], should therefore include gene level biodiversity as recognized by the Convention on Biological Diversity (CBD) to establish the FCS[29]. Research on identifying indicators for extinction debt at the regional level is urgently needed, as well as research on the effec-

21 The EU-ESFRI program LifeWatch (www.lifewatch.eu) aims to build on existing structures, networks and databases to achieve this goal

22 e.g. the degree to which community composition is governed by neutral versus niche differentiation processes; Hubbell 2001; Leibold et al. 2004

23 Elith et al. 2006; Phillips et al. 2006

24 Mayer & Pimm 1997

25 but see Pretzsch & Schütze 2009

26 Scherer-Lorenzen et al. 2007

27 extinction debt: a species that is on the way to extinction locally or regionally, but still occurs in some numbers in the region, .e.g. a species that cannot reproduce anymore because of habitat degradation, but is long-living and thus may remain in the habitat for quite some time before it fully disappears

28 Habitat Directive http://ec.europa.eu/environment/nature/legislation/habitatsdirective/index_en.htm

29 Laikre et al. 2009, 2010

tiveness of ecological networks to reduce extinctions at different spatial scales. Extinction debt due to non-equilibrium metapopulation[30] structure, in which local extinctions are not compensated by colonization, may apply to many taxa with ephemeral distributions, including amphibians, insects, branchiopods, and plants such as orchids with specific habitat characteristics. Metapopulation structure, with its influence on dispersal and colonization rates as well as local and regional effective population sizes, should be incorporated in the assessment of FCS. In marine systems, the impact of metapopulation structure on local populations is insufficiently studied, but may also be more important than often recognized.

Eco-evolutionary dynamics

17. In the last decade, much evidence has demonstrated that interactions between evolutionary and ecological processes may strongly impact evolutionary dynamics, population dynamics, community composition and ecosystem functions[31]. The first insights into these complex dynamics are fairly new but they are important to the understanding of biological responses to anthropogenic stress. This is especially the case for large-scale impacts such as climate change and the spread of invasive species. There is a need for the development of models on eco-evolutionary dynamics in realistic settings both in terms of species diversity (communities consisting of multiple species) as well as with respect to spatial and temporal scales (multiple patches with varying levels of connectivity). In addition, there is a need for large-scale experimentation as well as field studies quantifying changing eco-evolutionary dynamics for organisms that differ in reproduction cycle and generation time. In addition to studying eco-evolutionary dynamics at ecological time scales, there is also a need to incorporate phylogenetic signal and historical biogeography in our understanding of community composition at different spatial scales.

The challenge of species networks and identifying key players

18. Understanding the structure and functioning of multispecies interactions is essential to mitigate consequences of species losses and ensure persistence of complex ecological networks in diverse ecosystems[32]. Especially in microbial communities and in soil communities, complex interactions in which one species depends on the waste products of other species may strongly impact patterns of species composition across space and time. The same holds for the complex marine food webs that sustain fisheries and networks of species that have strong and species-specific interactions, such as in host-parasite, plant-pollinator, and other mutualistic interactions. It is often difficult to predict what the consequence of the extinction or massive reduction of a species would be for other species in the same system as well as for ecosystem functioning. How much functional redundancy is there among species in a system? There is a need for new theory and experimentation in community ecology that creates realistic, quantitative descriptions of natural networks and predicts and tests the consequences of their perturbation.

Challenges associated with complex dynamics and alternative stable states

19. Relationships between drivers and ecological responses are often non-linear, which can substantially increase complexity of their study and reduce predictability of responses[33]. For instance, global change and local drivers may force ecosystems to flip from one into another, unwanted stable state[34]. We need to identify precursors of ecological transitions, to be used as early-warning signals for catastrophic shifts between system states (cf. "tipping points"[35]). In addition, we need to understand mechanisms of resilience, key processes and interactions in ecosystems that lead to stabilized ecosystem states, as well as drivers that

30 A metapopulation is a set of populations inhabiting different habitat patches in a region; these local populations are characterized by strong local dynamics but are also influenced by the movement of individuals among populations inhabiting different patches; a metacommunity refers to the community of species that inhabit such sets of habitat patches in a region; again local community structure is then influenced by both local dynamics as well as dispersal of species among habitat patches (regional impact)

31 Thompson 2005 ; Urban et al. 2008

32 Bascompte & Jordano 2006; Memmott et al. 2006

33 Beninca et al. 2008

34 Scheffer 2009

35 Scheffer et al. 2009

may be used to force the system back into the desired equilibrium state[36]. To the extent that biodiversity has an important role in promoting resilience to environmental change, biodiversity loss may be an important factor inducing critical transitions[33].

C. Biodiversity, ecosystem functions and ecosystem services

Link between biodiversity, functional diversity and ecosystem functioning and ecosystem services

20. An increasing number of studies show a direct link between biodiversity and ecosystem functions. Biodiversity becomes especially important when different ecosystem functions are considered at the same time[37]. Similarly, biodiversity is expected to play an important role in increasing resilience of ecosystems to environmental change and anthropogenic impact. With an increasing number of functionally different species, the probability increases that some of these species can respond in a differentiated manner to the external perturbations or changing environmental conditions. In addition, the probability increases that one species can take over the role of another, redundant species that does not survive the disturbance or new conditions[38]. There is, however a need for better insight into the precise relationships between biodiversity and ecosystem function. This entails identification of indicators for critical levels of biodiversity loss that are associated with the collapse of ecosystem functions.

Ecosystem services at landscape level

21. Regional biodiversity is a function of both local biodiversity in the different patches as well as of species turnover across patches. Similarly, ecosystem services need to be viewed at the regional level, taking complementary services across localities into account. There is a need to map ecosystem services at the landscape level and to link them to patterns of biodiversity, to identify the degree to which protection of biodiversity at the landscape level will result in maximum protection of ecosystem services. Protocols need to be developed on how to best combine the information on biodiversity and ecosystem services in prioritizing areas for protection. For maximizing regional diversity, it is often important to also protect areas of relatively low local biodiversity that harbour characteristic organisms (e.g. salt marshes and heath lands). At a global scale, this is illustrated by the importance of islands for biodiversity conservation.

Economics of biodiversity and ecosystem services

22. Ecosystems and biodiversity, as many environmental issues, are strongly subject to the rule of "tragedy of the commons": as these services are provided for free, they are not valued and are therefore often harvested or impacted in a non-sustainable way, as is the case for overfishing. We need to develop systems in which the loss of ecosystem services due to (economic) activities is paid by the agent causing the loss instead of the society as a whole (i.e. the tax payer), and where providers of ecosystem services are rewarded for their activities or compensated for reduced income compared to traditional management[39]. This requires research on how this can be realized in practice, as well as research quantifying the economic impact of ecosystems and species, such as is currently underway in The Economics of Ecosystems and Biodiversity initiative[40].

D. Understanding how species respond to anthropogenic impact

23. A number of *land-use changes*, such as urbanization and clearing of forest for agricultural land, threaten native biodiversity through habitat destruction, degradation and fragmentation. Changes in the way humans use agricultural land, e.g. cessation of traditional agricultural practices and abandonment of agricultural land, has also led to impoverished biodiversity and landscapes. Similarly, man's activities have

36 Van Leeuwen et al. 2008
37 Hector & Bagchi 2007
38 Yachi and Loreau, 1999
39 Wunder et al. 2008
40 TEEB 2009; http://www.teebweb.org/

affected the physical structure of marine habitats (e.g. by trawling or drilling), thus inducing changes in ecosystem structure. We urgently need research to better quantify and understand the extent and consequences of these changes to develop a basis for restoration and the sustainable use of biodiversity.

24. While *harvesting/exploitation* of terrestrial ecosystems in Europe has been fairly well under control in recent decades, the industrialization of fisheries has lead to severe overharvesting of many marine species, either through their direct exploitation or through the incidental, non-intentional catch of non-target species. Large top predators have particularly suffered from this impact and have vanished or been much reduced from oceanic food webs, with cascading effects on the ecosystem. Current procedures and regulations to manage fishing are clearly ineffective and research should focus on the understanding of fishing interactions with biodiversity, identifying the hidden effects of fishing and developing more accurate and practical management frameworks, and abandon perverse subsidies for unsustainable practices[41].

25. *Invasive non-indigenous species* are considered the second-largest threat to biodiversity. Exotic species control and eradication programmes are increasingly needed, but often very labour intensive and expensive. There is a need to compare this cost, as well as the costs of preventive actions, with the expected harm to the recipient ecosystem. Invasive exotic species elicit strong biological responses, as co-evolved interactions among species are being disrupted and new interactions are being established. This comprises responses at the population (including micro-evolutionary changes) and at the community level, and research is needed in order to find the Achilles' heel of the invader – if it exists. In these analyses, it is also important to take the loss of ecosystem services caused by invasive species into account. Climate change may favour the invasion of exotic species, and there is a need to integrate both local and regional processes to evaluate its effects at higher spatial scales.

26. *Climate change* has a profound impact on populations and communities. Climate envelope predictions need to be modulated with feedback responses due to changed interactions among species and micro-evolutionary change. They also need to explicitly take dispersal limitation into account, and the interplay of local and regional dynamics. Biodiversity may be affected by policies that aim to mitigate climate change. For example in forests, increasing carbon sequestration through long rotations and retention of structural elements such as dead wood will greatly enhance the habitat values of European forests[42]. These forests are largely considered to be semi-natural, reflecting the long history of human use and forestry. However, forest ecosystems are naturally dynamic, and the accumulation of large amounts of biomass may also lead to greater risks, also for biodiversity and ecosystem services, for example through high intensity fires. Our knowledge about these interactions between ecosystem development, climate change and disturbances is still fairly limited[43].

E. Understanding how species respond to nature conservation measures

Linking ecological concepts to biodiversity conservation and nature restoration projects

27. In our efforts to conserve biodiversity, many management plans are being implemented, in line with international policies and legislation, such as Natura2000, and the Birds, Habitats, and Water Framework Directives. Protected areas are being created, networks of nature reserves, buffer zones and corridors are planned, and nature restoration projects are launched. However, it is not always apparent what the consequences are of these plans for complex biological communities and the biodiversity they harbour. There is a continued need to fine-tune our insight into processes relevant to biodiversity conservation as well as their translation into nature conservation policies. Building on the MacArthur-Wilson island biogeography model, research in the past two decades has stressed the importance of metapopulation dynamics in maintaining diversity, thus providing guidelines for biodiversity conservation policy in and outside (terrestrial) reserves. A better understanding of eco-evolutionary dynamic processes will provide a more encompassing framework for biodiversity conservation policies that takes landscape structure, conservation genetics, micro-evolution, community struc-

41 Pauly et al. 2003
42 Bauhus et al. 2009
43 Larsson et al. 2007

ture, evolutionary position and uniqueness of species, biodiversity and ecosystem functions into account.

The translation of these ecological concepts into conservation policy of marine biodiversity is as yet poorly developed. Given the state of our oceans and the establishment of marine reserves in many places, it becomes crucial to apply the concepts developed in conservation of terrestrial biodiversity to marine systems, and adapt them where needed.

28. Nature management can also have unanticipated side effects. For instance, nature restoration may unintentionally promote dominance of opportunistic or invasive species, simply because these may reach novel habitat patches first and may monopolize resources, leaving less room for target species to establish viable populations. Strategies to counteract these negative dynamics must be formulated to promote the development of reconstructed nature with high levels of native biodiversity and ecosystem integrity. A critical decision also relates to the choice between conserving biodiversity in reserves/pristine areas and trying to conserve biodiversity in land used for other functions such as urban development and agriculture.

Ex-situ conservation of genes and "seeds"

29. Although the conservation of natural areas is the preferred way of conserving biodiversity, amongst others because of its cost-effectiveness and because of the importance to preserve ecosystem services, ex-situ conservation of genes, tissue or dormant stages ("seeds") is needed to provide a safeguard in case species or genetic races disappear from the wild. This can be done by the establishment of seed banks as well as repositories for tissues and germ cells. The Millennium Seed Bank at Kew focuses on non-crop plants and has banked seeds of 20% of plant species, whereas the Svalbard Global Seed Vault at this moment already contains >250.000 seed samples from crop varieties of all over the world. Storage of vegetatively propagated species requires more sophisticated techniques such as cryopreservation. Although "fixed" storage of genetic material may be an important safeguard, it should also be realized that preserving existing genetic variation is not sufficient to protect evolutionary potential for the future. Large-scale gene, seed and soma preservation does not reduce the importance to preserve natural dynamics of selection and micro-evolution. The latter can be supported by preserving habitats (including small-scale farming for crops and breeds) in which organisms are subject to natural dynamics of changing selection pressures.

Socio-economics of biodiversity conservation at different spatial and temporal scales

30. Conservation policies cannot be effective without taking socio-economic factors into account. Policy options range from the full protection of large-scale landscapes or strict protection plans for specific species to leaving the development to all stakeholders and users. There is a need for studies quantifying the risks and effectiveness of the different options. Importantly, these studies should consider costs and benefits to society at local, regional and global scales, and both for short-term and long-term perspectives. It may be that although benefits of protection are much higher than costs in the long term, short term benefits will dictate the developments. If so, a possible option is to use this information to create temporary compensation measures for local communities to cover the incurred loss. Such policies seem to be needed for marine systems, e.g. with respect to the protection of fish stocks and marine biodiversity. Also, studies need to focus on the possibilities for complementary ecosystem management outside protected areas, or other types of compensatory actions in a world dominated by a still increasing human population.

IV. Recommendations

31. In the above paragraphs, building blocks are presented that will have to become part of the biodiversity research agenda for the decades to come, in order to allow Europe to implement the 2050 vision and reach the 2020 targets. Different types of actions are required to accomplish effective biodiversity conservation strategies, involving research scientists, policy makers, stakeholders and the general public. Key requirements for an effective biodiversity conservation policy are listed hereafter, structured in four areas: (i) research priorities, (ii) policies, (iii) collaboration, and (iv) education and awareness. Several of these recommendation are in line with the "Cibeles" priorities[6] already introduced (Box 1).

A. Recommendations on research policies for biodiversity management

Invest in a European infrastructure for biodiversity data and research

32. Europe must invest in adequate infrastructures to support biodiversity research to increase our knowledge of the impact of biodiversity on the functioning of ecosystems and hence help decision makers in devising cost-effective management plans to reach the stated goals. This comprises support for taxonomic facilities for species identification, new techniques for identification of (micro-)organisms (for instance using genetic barcodes), monitoring programmes for changes in the distribution of species, long term ecological research (LTER) sites, National Ecological Observation Networks, and sites for experimental biodiversity research. European-wide biodiversity infrastructures, such as the ESFRI ´LifeWatch´ project, are of key importance. Interoperable databases using adopted standards as well as tools and expertises to use the data are needed.

Invest strongly in enhancing fundamental knowledge on biodiversity drivers and threats

33. There is an urgent need for a better knowledge of the dynamics of ecosystems, the drivers of unwanted changes, the development of early warning signals, the threats for biodiversity, and, finally, the consequences of changes in biodiversity for ecosystem functioning and ecosystem services; i.e. there is a need for an ambitious research agenda with focus on knowledge gaps as identified in "Research Challenges". It is crucial to use all power and insight that exists today to slow down or halt the loss of biodiversity and optimize conservation policies. At the same time, there is a need to be alert and open-minded for implementing new ideas and concepts in order to maximize effectiveness of conservation policies in the future. A vigorous biodiversity-targeted research programme is called for, initiated at the European level but also with strong national support.

Effective translation of scientific knowledge into biodiversity practice

34. There is a great need to ensure that the scientific evidence is available to practitioners, as it is currently underused. The development of evidence-based conservation[44] provides a process for basing action upon science by summarizing the available information in a more readily useable manner[45].
New regulations and nature conservation practice should take eco-evolutionary dynamics as well as ecological complexity into account in dealing with responses to climate change, exotic invasive species and other stressors, with an open eye for possible detrimental side-effects on non-target species, and the dynamics at different spatial scales. This will lead to new policies, different for fragmented and non-fragmented landscapes, taking metapopulation and metacommunity aspects into account, and consider dynamic rather than static targets for conservation. In some cases, targeted whole community re-introductions and "seeding" novel habitats may be better options than waiting for natural recolonization.

B. Biodiversity conservation policy recommendations

A consistent and global biodiversity conservation policy

35. There is a need for strong regulation and incentives, clear targets, clear aims for habitat restoration and the preservation of landscape structure, the establishment of large protected areas, including marine systems, and the promotion of biodiversity for ecosystem functioning in production systems. There is also a need for regulation targeted at non-protected areas. Currently there are many inconsistencies between biodiversity policy and other policies. To avoid these, biodiversity conservation policy needs to be developed as part of food security, land use, climate change and energy policy, and should not be separated from these.

44 Sutherland et al. 2004

45 This recommendation also relates to the "Cibeles" priority: 'To boost the integration of scientific knowledge into decision making processes.', and is also mentioned in the Global Biodiversity Outlook 3 of the CBD.

36. The consequences of the way of living and certain policies and practices on systems beyond European borders should be taken into consideration. For example, the importance of rain forest conservation, coral reefs, the functioning of our oceans and the arctic, the protection of world heritage sites and hot spots of biodiversity and ecosystem services should be a focus point in general policy. The EU policy on biofuels, for example, has important consequences for deforestation in South-East Asia. Similarly, European fisheries policy impacts marine ecosystems and fishing resources worldwide. This recommendation on a global perspective is in line with the seventh "Cibeles" priority [46], but is more extensive as it includes reconsidering European policies and fostering change in the way people live and work in Europe to ensure biodiversity conservation also outside Europe's borders.

A "biodiversity check" in all policies

37. Given that biodiversity and ecosystem services are of paramount importance to the development of human societies in the long run, there is a need for reflection during policy development on the impact of that policy on biodiversity, ecosystem function and climate change. There should be a proper protocol on how to evaluate costs and gains of policies that take ecosystem services into account[47]. Both policy makers and researchers failed to foresee the economic, ecological and climate change consequences of the promotion of biofuels by the EU and US. One solution is routine horizon scanning[8] to increase the likelihood that the research results will be available when required by policymakers.

A climate change-proof biodiversity conservation policy

38. In developing a biodiversity conservation strategy, there is a need for checking whether the measures taken are climate change-proof. Climate change will impose strong challenges on biodiversity conservation. Any policy on biodiversity conservation should therefore also take the impact of climate change on the effectiveness of the policy into account.

Quantify economic consequences of biodiversity losses and gains

39. A protocol must be developed to charge for activities that reduce ecosystem services on the long run (based on consensus agreement)[48]. The resources earned by this measure should be invested into conservation management and ecosystem restoration. In the future, the loss of ecosystem services due to (economic) activities should be paid by the agent causing the loss instead of the society as a whole (i.e., the tax payer). This general concept requires, however, international agreements and guidelines[49].

A European strategy to deal with invasive exotic species

40. By far the most efficient strategy to reduce the impact of invasive species is prevention[50]. With regards to prevention of the introduction of exotic and possibly invasive species, there is a need to define an overarching European strategy. This requires amendments in the legal European framework, and a harmonisation of the free trade of goods within Schengen countries with European implementation of the CBD and the precautionary principle regarding non-indigenous species.

C. Fostering collaboration

Support for multidisciplinary collaborative networks

41. Modern biodiversity research requires that teams of experts from different fields work together. Analysing complex systems and heterogeneous data require not only expertises in biology, but also in informatics, modelling, climatology, hydrology, and

46 cf. "Cibeles" priority 'To support the establishment and management of protected areas and ecological networks in third countries'

47 This recommendation aligns with two of the 10 "Cibeles" priorities: 'To incorporate the objectives and targets for biodiversity as part of the European Union Strategy for 2020' and 'To deepen the integration of biodiversity into agriculture, fishing, energy, transport and development policies.'

48 Fisher et al. 2008

49 The idea of quantifying the economic consequences of biodiversity losses and gains aligns with the "Cibeles" priority nr 2 'To ensure payment of ecosystem services'.

50 Myers et al. 2000

more. Moreover, effective solutions to reach the biodiversity goals cannot be found without taking the socio-economic aspects into account. Networks and training programmes that bring together people from different scientific disciplines, as well as stakeholders and policy makers, must be stimulated. In addition, Europe wide research training networks for biodiversity research would greatly aid to establish the required connection and synthesis in biodiversity research whilst providing a long-needed platform for inter- and transdisciplinary training of young scholars.

An improved science-policy interface in biodiversity protection

42. There already is an initiative to establish an Intergovernmental platform on Biodiversity and Ecosystem Services (IPBES)[51]. This platform should become a powerful tool to turn scientific insights to practices, to inform the general public, to gain media attention for the fight against biodiversity loss, and to streamline large-scale research efforts.

D. Biodiversity education and awareness

43. No biodiversity policy can succeed without proper support from the general community. There is a need to invest in education programmes aimed to increase the EU citizens' understanding and awareness of biodiversity decline and its consequences. Concerted efforts at the European level are advisable, and research-intensive universities should play a leading role in this. The concepts of biodiversity and their importance are complex but can effectively be transmitted to young and non-expert people. Involvement of layman and volunteers in biodiversity research (*Citizen Science*), for instance using the modern technologies provided by the internet, can be an effective way to increase knowledge and awareness.

V. Role of research-intensive universities

44. The conclusion of this report is that a substantial investment in biodiversity research, infrastructure and education is urgently needed in order to meet the challenge of halting biodiversity loss. Research-intensive universities can contribute substantially to this by implementing an ambitious biodiversity research agenda, in line with the recommendations outlined above. Furthermore, inter-university networks should make the use of research infrastructures effective and efficient, and boost multidisciplinary approaches to the complex challenges posed by the interaction between biodiversity, global change and society. LERU also acknowledges the need to invest in biodiversity education, intends to develop education programmes to fulfil their responsibility, and to foster cooperation in inter-university (e.g. Erasmus Mundus) programmes.
The challenges for biodiversity research in Europe require a strong commitment from research universities, but also support from national and supranational organisations. LERU considers the study of biodiversity and the ecological responses to environmental change a top research priority with an enormous added value to society.

51 The EU is supporting efforts to establish an IPBES (COM(2010)4). The decision for setting up an IPBES will be taken at the third and final IPBES meeting in June 2010, in Korea (http://ipbes.net/)

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About LERU

LERU was founded in 2002 as an association of research-intensive universities sharing the values of high-quality teaching in an environment of internationally competitive research. The League is committed to: education through an awareness of the frontiers of human understanding; the creation of new knowledge through basic research, which is the ultimate source of innovation in society; the promotion of research across a broad front, which creates a unique capacity to reconfigure activities in response to new opportunities and problems. The purpose of the League is to advocate these values, to influence policy in Europe and to develop best practice through mutual exchange of experience.

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